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FINAL REPORT FOR RESEARCH AGREEMENT
#INT-92684-RJVA
"Response of Willow and Bitterbrush to Shelterwood Cutting and Underburning Treatments in a Ponderosa Pine Forest"
UNIVERSITY OF MONTANA
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FINAL REPORT

RESPONSE OF WILLOW AND BITTERBRUSH TO SHELTERWOOD CUTTING AND UNDERBURNING TREATMENTS IN A PONDEROSA PINE FOREST

RESEARCH JOINT VENTURE AGREEMENT NO. INT-92684-RJVA

BETWEEN

U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE,

INTERMOUNTAIN RESEARCH STATION AND THE

UNIVERSITY OF MONTANA

By

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INTRODUCTION

Antelope bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) are important browse species found in many western Montana ponderosa pine (*Pinus ponderosa*) stands . These species are often the most preferred browse for wild ungulates such as mule deer (*Odocoileus hemionus*) (Wilkins 1957), elk (*Cervus elaphus*) (Leege 1979), bighorn sheep (*Ovis canadensis*) (Welch et al 1982), and moose (*Alces alces*) (Pierce 1984), as well as domestic ungulates. Early photographs provide evidence that ponderosa pine stands were historically more open and spatially patterned by fire (Gruell et al 1982). Since the late 1800's fire suppression and selective logging in ponderosa pine stands have resulted in forest stands with dense Douglas-fir (*Pseudotsuga menziesii*) with unknown affects on browse production and quality of bitterbrush and Scouler's willow.

The large-scale successional replacement of ponderosa pine by Douglas-fir may be undesirable because fir are more susceptible to disease and outbreaks of defoliating insects, fir forests are usually more "closed" with a subsequent reduction in vigor and biomass of understory vegetation, and these forests are more prone to stand replacement fires. The possibilities of using prescribed fire as a silvicultural tool in ponderosa pine forests have been discussed by several authors. Reduction of Douglas-fir and an increase in ponderosa pine may improve future timber production, improve quality and quantity of forage for domestic and wild ungulates, and may reduce fire hazard. Several studies have shown an increase in vigor and biomass of browse plants following shelterwood cutting (McConnell and Smith 1977, Stuth and Winward

1976, Edgerton 1982) and prescribed burning (Driver et al. 1980, Owens 1980, Oswald and Covington 1984, among others). Without disturbance bitterbrush declines in density and vigor (Sherman and Chilcote 1972); silvicultural treatments such as thinning (McConnell and Smith 1977, Stuth and Winward 1976, Edgerton 1982) have been more effective than burning (Clark et al 1982, Kituku et al 1992, Cook et al 1994) in enhancing the quality of bitterbrush as browse. For willow, burning has been effective in enhancing vigorous regrowth (Mueggler 1965, Leege 1972,1979, Asherin 1973, Stickney 1986, Noste and Bushey 1987) and germination (Fischer and Bradley 1987). Little is known of the effects of logging on willow.

The ecological aspects of forestry practices on all resources, including the use of fire as a restoration tool, is of great interest to land managers. However, the combined effects of harvesting and burning on survival, vigor and biomass have not been examined for most browse species (Peek et al 1978, Gruell et al 1982, Arno 1988). Therefore, the general objective of this study was to determine the effects of new perspectives silviculture and fire treatments on wildlife habitat. The specific objectives were:

(1) To determine the effects of a shelterwood cut and prescribed treatments on the survival and seedling establishment of Scouler's willow and bitterbrush; and,

(2) To determine the effects of a shelterwood cut and prescribed fire treatments on leaf and twig production and nutritive value of bitterbrush and Scouler's willow.

Information on available biomass and vigor, a measure of productivity and reproductive fecundity, have been used in plant-herbivore research to indicate browse quality (Rutherford 1979). This study provides land managers with information on the response of bitterbrush and willow to potential silviculture treatments under consideration in western Montana.

STUDY AREA

The study area was the Lick Creek Study Area (LCSA) of the Bitterroot National Forest in Ravalli County, Montana. The area is 3 km north of Lake Como and 15 km south of Hamilton, Montana. Elevation on the south-east facing slopes ranges from 1300 to 1500 m. Precipitation averages 56 cm/yr, with approximately 50% as snow (Gruell et al 1982). November through March temperatures average -2 °C, and ranged from -28° to 12 °C during those months in 1993 and 1994. Mid-May through mid-September temperatures average 20 °C, and ranged from -2° to 32 °C during those months in 1993 (USFS Intermountain Fire Laboratory, 1995). The soils are derived from granitic parent materials and are shallow to moderately deep. Clumps of Scouler willow and bitterbrush are common but of very low productivity as a result of suppression by the conifer stand.

Stand entry for selective timber harvest has occurred several times over the last 90 years in the LCSA. Removal of ponderosa pine from the overstory has resulted in an increase of Douglas-fir (Arno 1991). Trees on the research site are primarily even-aged, which established after a 1906 clear cut (Gruell et al. 1982). Tree basal area

averaged 28.0 m^2/ha before harvesting in 1992 and radial growth of trees had slowed significantly in the last 20 years as a result of heavy stocking (Arno 1991). Habitat types vary across the site from *Pseudotsuga mensieziil/Vaccinium caespitosum* on toe slopes and benches to *Pseudotsuga mensiezii/Symphoricarpos albus, Agropyron spicatum* phase (Pfister et al. 1977) on drier south-facing slopes. LCSA is an important winter range for white-tailed deer (*Odocoileus virginianus*), mule deer, Rocky Mountain elk, and moose.

METHODS

TREATMENTS

The study site was divided into 12 approximately equal units of 4 ha by personnel from the Fire Sciences Lab. Each unit was assigned to one of the following four treatments: (1) a shelterwood cut, (2) a shelterwood cut and a high fuel consumption burn, (3) a shelterwood cut and a low fuel consumption burn, and (4) a control.

The shelterwood cut was completed in the fall of 1992. Tree harvesting reduced the average tree basal area by 53% to 13.1 m^2/ha. Prescribed burns were conducted in May 1993 by personnel of the Intermountain Fire Sciences Lab and Bitterroot National Forest (see Appendix A).

Mechanical Damage, Vigor, Survival and Seedling Establishment

Substudy 1. Before application of treatments, 12, 400-m^2 (11.25 m radius) plots were systematically located in each unit and permanently marked with a steel spike by

Intermountain Fire Sciences Lab personnel (see Appendix B). In the summer of 1992 we located 893 willow plants and 1,903 bitterbrush plants in these 144 plots. For each plant we recorded distance and azimuth from the center of each plot, plant height, diameter at mid-canopy, diameter of largest basal stem, and a dead class rating (as an estimated of plant vigor pre-treatment). The classes were (1) <5% of plant dead, (2) 5-25% of plant dead, (3) 25-50% of plant dead, (4) 50-75% of plant dead, and (5) > 75%of plant dead.

Bitterbrush and willow were relocated following the shelterwood cut to determine mechanical damage and current fuel loading around shrubs. Mechanical damage was assessed using 6 subjective classes: (0) no damage, (1) light damage (minor damage to a few stems, (2) moderate damage (damage clearly visible as broken stems but at least ½ of the plant not damaged), (3) high damage, (over ½ of the plant suffering broken stems), (4) severe damage (most of plant missing, generally only the top portion of the crown remaining). We also recorded if the plant was missing which was generally associated with skid trails (class 5). Fuel loading was assessed using 5 classes: (0) mineral soil at the base of the plant and little chance of fire affecting the crown or base of the plant; (1) light-natural fuels (fuels that may carry the fire into the main stem of the plant, (2) moderate natural fuels (fuel level that would be expected to carry the fire into the main stem, (3) high-natural (fuel levels would be expected to burn the main stem and the fuels would be expected to burn for a longer period of time, and (4) high natural with added fuels (same as class 3 but with slash added to the area adjacent to the base of the plant).

Burn class was determined following prescribed burns plants in the Spring of 1993. Burn class was assessed using 5 classes: (0) no evidence of fire damage, (1) slight fire damage at base of plant, (2) base of plant burned with many stems scorched or burned, (3) only the base of the plant remaining, and (4) the plant completely consumed by fire. Vigor and survival of plants were measured in late summer of both 1993 and 1994. Vigor was assessed similar to Buwai and Trlica (1977) using 3 classes based on a proportion of current annual growth (CAG) meeting a minimum twig length of 5 cm and 10 cm for bitterbrush and willow, respectively (Lyon 1968):(1) >67% of CAG, (2) >33% and <67% of CAG, and (3) <33% of CAG.

Substudy 2. Following the shelterwood cut additional willow and bitterbrush were selected for more detailed monitoring of fire effects on twig production and nutrient content of winter twigs. These plants were also photographed for a record of their response to treatment over time. Five willow and 5 bitterbrush were selected in each treatment with either heavy natural fuel or heavy natural fuel with added fuel (created by placing woody fuel at the base of the plant). An additional 5 bitterbrush with a light natural fuel treatment was also included, but we did not believe there were enough willows in the light natural fuel class for measurement. Location of each plant was permanently marked, the plant photographed, and duff depth measured and fuel loading were estimated by Intermountain Fire Sciences Lab personnel.

Pre-treatment measurements and post-burn measurements were the same as for substudy 1. None of these plants had mechanical damage from the shelterwood

cut. At the end of the growing season in 1993 and 1994, plants were relocated to measure survival and biomass. Dry weight biomass of current annual growth (CAG) was determined using an ocular estimation technique (Rutherford 1979).

Nutrition Analyses

Bitterbrush and willow twigs were collected in February during 1994 and February and April 1995 to represent winter nutrition levels of twigs. Twig samples were collected by clipping the previous seasons growth and placing into a marked bag. Twig samples were collected from 5 representative plants on each treatment. Samples were transported back to Missoula and immediately placed in a forced air convection oven set at a temperature of 110^{0}C for approximately 10 minutes and then dried for 96 hours at 65^{0}C. Samples were stored until time for nutrition analysis.

The Plant Nutrition Lab at Colorado State University completed all nutrition analyses. Twigs were analyzed for carbon (%), nitrogen (%), ash (%), phosphorus (ppm), protein (%), lignin (%), acid detergent fiber (ADF, %), cellulose (%), and organic matter (%).

Two significant problems occurred with samples collected for nutrition analyses. First, in 1994 it was determined that there was not sufficient twig material available for burned bitterbrush because of the combined effects of the burning and browsing. Therefore, this treatment was not sampled in 1994. Second, during March 1995 a significant proportion of samples were mistakenly discarded from our lab. We collected additional samples on April 1, 1995, but it was impossible to replace 1994 samples.

Therefore, in 1994 there were 3, 2, 4 and 4 willow samples for the high consumption, low consumption, no burn and control treatments, respectively. Additional burned willow samples were collected above our experimental unit on a site that had been burned the previous growing season and is listed as treatment early burn. As stated previously, we did not believe there was adequate bitterbrush biomass (clipping of material would potentially have negative influence on the plant) available for the burn treatments in the winter following the prescribed burn in 1994 and there were only 4 samples available in the no burn and control treatments. In the second winter following burn there were three samples analyzed for the burn treatments and four samples for the no burn and control treatments. Because of the small sample sizes the burn treatments were combined for data analysis.

EXPERIMENTAL DESIGN AND DATA ANALYSIS

The experimental design was a completely randomized design with 3 replications/treatment. Because many plants did not burn within the prescribed fire treatments, plants were also grouped for analyses into burned and unburned categories according to fire exposure. Using logistic regression (Sokal and Rohlf 1995) mortality for each group was predicted using variables of height, diameter, dead class, mechanical damage, fuel loading and burn class. Post-treatment vigor was correlated with these factors using Kendall-tau non-parametric correlation analysis (Sokal and Rohlf 1995). Survival of the numbered plants based on fuel loading was compared between burn treatments using Chi-square analysis (Sokal and Rohlf 1995).

Differences in biomass among treatments were analyzed using analysis of variance and orthogonal contrasts (Sokal and Rohlf 1995). Differences were considered significant at $P<0.05$.

RESULTS

The results are presented according to sub-study. For substudy 1 results are presented in three sections. First, the damage to bitterbrush and willow resulting from the shelterwood cut is presented. This includes damage associated with the shelterwood cut for the no burn, low consumption, and high consumption burn treatments before burning. It also includes results of plants damaged by the shelterwood cut that did not receive damage by burning in the burn treatments. Second, the results of the influence of the prescribed burn treatments are presented for those plants that burned. The third section of substudy one provides results of the treatment differences associated with the no burn, low consumption and high consumption burn treatments irrespective of ~~rather~~ whether or not the plants burned.

Sub Study 1. Influence of the shelterwood-cut and burning on survival, vigor and seedling establishment of bitterbrush and willow on permanently established plots.

Shelterwood cut. The stand entry resulted in significant plant damage to bitterbrush and willow with a significant loss of plants (Tables 1 and 2). The loss of plants associated with the timber harvesting was the result of the complete removal of

Table 1. Influence of timber harvesting on plant loss (%) and plant damage (%) of bitterbrush (*Purshia tridentata*) (spring 1993).

TREATMENT[1]	LOSS (%)[2]	MECHANICAL DAMAGE RATING (%)				
		None	Low	Moderate	High	Severe
HIGH CONSUMPTION	31	32	13	12	9	3
LOW CONSUMPTION	17	29	17	20	14	3
NO BURN	27	50	6	6	6	5

[1]Plant damage measured on burn treatments before the application of the burns.
[2]Plant loss is the percentage of plants not found immediately after the shelterwood cut. This figure is not equal to mortality since some plants may have resprouted and damaged plants found may not have survived into 1994.

Table 2. Influence of timber harvesting on plant loss (%) and plant damage (%) to Scouler's willow (*Salix scouleriana*) (spring 1993).

TREATMENT[1]	Loss (%)[2]	MECHANICAL DAMAGE RATING (%)				
		None	Low	Moderate	High	Severe
HIGH CONSUMPTION BURN	16	18	27	20	13	7
LOW CONSUMPTION BURN	13	26	23	18	14	6
NO BURN	9	26	13	13	16	22

[1]Plant damage measured on burn treatments before the application of the burns.
[2]Plant loss is the percentage of plants not found immediately after the shelterwood cut. This figure is not equal to mortality since some plants may have resprouted and damaged plants found may not have survived into 1994.

shrub crowns in skid trails. Missing willow plants (%) following stand entry was less than that of bitterbrush averaging 12.7% and 25%, respectively. The greater loss of bitterbrush is a result of its growth habit (single main stem) which allows it to be easily uprooted by skidding trees over bitterbrush or equipment breaking off the main stem at ground level. Plants without mechanical damage (%) was greater for bitterbrush compared to willow, averaging 37% and 23 %, respectively across treatments; however, this is probably associated with individual willow plants averaging more area (greater individual plant size) than the bitterbrush plants.

At the end of the 1994 growing season it was determined that of the 1217 bitterbrush and 534 willow in a treatment receiving a shelterwood cut (but the plants did not receive fire damage) mortality was 35% and 13%, respectively (Table 3). Logistic regression was used to identify which independent variables explained a significant amount of the variation in mortality of bitterbrush and willow. For plants not exposed to fire the greatest variation in plant mortality was accounted for by mechanical damage (Table 3) where skidding removed 46% and 65% of the variation in bitterbrush and willow mortality, respectively. Of the plants that were removed by skidding or received a severe mechanical damage rating, 90% of the bitterbrush and 60% of the willow died (Fig. 1).

Burn Treatments. The responses of bitterbrush and willow to the burn treatments were confounded by mechanical damage and variation in burning severity. For example, 21% and 30% of the bitterbrush plants remaining after the shelterwood harvest did not burn in the low consumption and high consumption burn treatments, respectively (Table

Table 3. Significant variables[1] explaining bitterbrush (*Purshia tridentata*) and willow (*Salix scouleriana*) mortality in LCSA, 1995 for plants exposed or not exposed to fire.

Species	Exposure	#Dead (N)	Variable	Variance	Significance
Bitterbrush	Fire	459 (639)	Burn class	72%	X^2=78.3 df=3
			Fuel loading	+2%	X^2=24.5, df=4
			Dead class	+2%	X^2=20.3, df=5
			Height	+1%	X^2 =9.2 df=1
	No fire	425 (1217)	Mech. Damage	91%	X^2=852 df=5
Willow	Fire	65 (337)	Burn class	84%	X^2=31.1 df=3
	No fire	68 (534)	Mech. damage	90%	X^2=126 df=5

[1]Variables tested were height, diameter, dead class, mechanical damage, fuel loading, and burn class (variables significant at $p<0.001$).

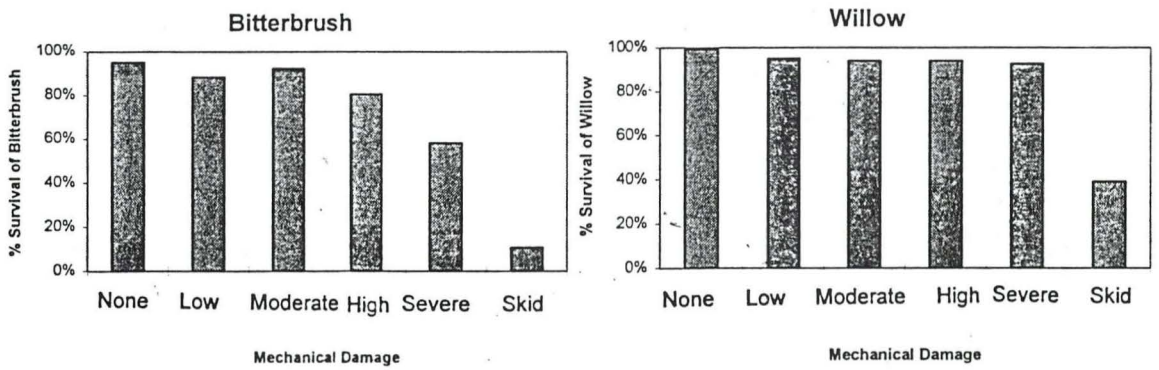

Fig. 1. Survival of antelope bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants not exposed to fire, Lick Creek Demonstration Area, 1994.

4). For bitterbrush there was a greater proportion of plants in higher burn damage classes (greater burn damage) for the low consumption burn treatment as compared to the high consumption burn treatment. This was surprising since after the shelterwood cut fuel loading adjacent to bitterbrush and willow were similar for burn treatments (Table 5).

For willow and bitterbrush exposed to fire, mortality was best explained by the degree of burn severity (Table 3). Of the 639 bitterbrush plants that were burned only 28% survived and mortality was related to burn class (Fig. 2). For bitterbrush that received burn damage (burn class low to severe) mortality was greater for the high consumption treatment (Fig. 2). Bitterbrush mortality was also surprisingly high for the low burn class showing that bitterbrush on this site was very sensitive to fire.

Bitterbrush mortality was also significantly correlated to fuel loading, dead class, and height, but only very weakly (Table 3). For example, the relationship of fuel load to bitterbrush and willow mortality are shown in Table 6. As fuel load increased mortality generally increased (fuel load class 0 for bitterbrush had a high percentage of mortality but the actual number of plants that received burn damage in this class was very low).

Of the 337 willow plants that received burn damage survival was 80% (Table 3). Willow mortality increased as burn damage increased, but mortality was significant only in the severe burn class and there was no difference between the burn treatments by burn class (Fig. 2).

Table 4. Proportion (%) of bitterbrush and Scouler's willow plants in the low consumption burn (LCB) and high consumption burn (HCB) treatments by burn class.

SPECIES/ TREATMENT	BURN DAMAGE None	Light	Moderate	Severe	~~Very~~ Severe
BITTERBRUSH (%)					
LCB	20.6	19.8	18.4	27.1	14.1
HCB	30.0	34.0	10.9	19.5	5.5
WILLOW (%)					
LCB	2.9	5.4	21.1	65.2	5.4
HCB	5.4	8.2	17.0	62.6	6.8

Table 5. Bitterbrush and Scouler's willow (%) by fuel loading class for the low consumption burn (LCB) and high consumption burn (HCB) treatments after the shelterwood cut.

SPECIES/ TREATMENT	FUEL LOADING CLASS None	Light	Moderate	~~Severe~~	~~Very Severe~~
BITTERBRUSH					
LCB	4.2	29.7	34.7	26.3	5.1
HCB	5.3	21.3	32.4	31.6	9.4
WILLOW					
LCB	1.5	6.4	28.9	48.5	14.7
HCB	1.4	6.1	12.9	55.8	23.8

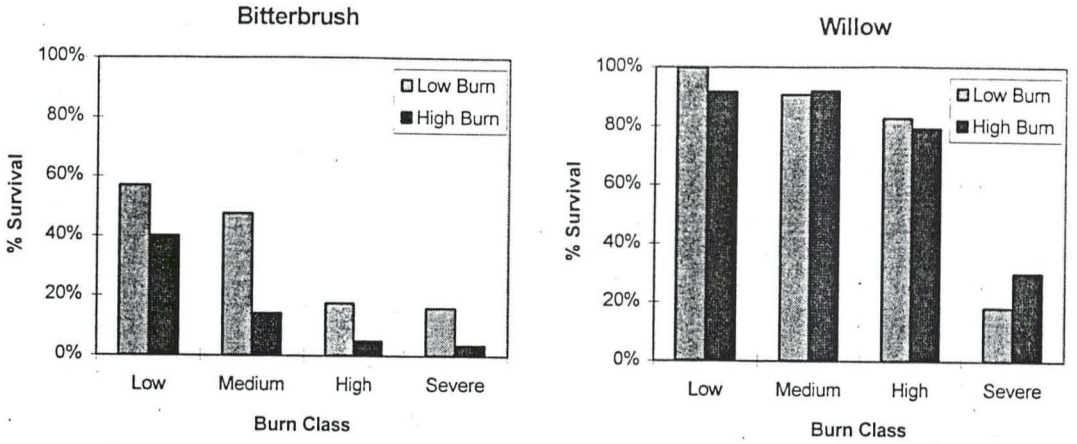

Fig. 2. Survival of antelope bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants by burn class for low and high consumption burn treatments, Lick Creek Demonstration Area, 1994.

Table 6. Influence of type of burn and fuel load on mortality (%) of bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants which received burn damage on the permanently established 0.10 acre plots.

TREATMENT	FUEL LOAD CLASS	PERCENT MORTALITY BITTERBRUSH	SCOULER'S WILLOW
HIGH CONSUMPTION BURN	0	83 (5)[1]	nd[2]
	1	70 (28)	11 (1)
	2	67 (81)	11 (2)
	3	79 (115)	59 (16)
	4	98 (45)	49 (11)
LOW CONSUMPTION BURN	0	67 (2)	nd
	1	45 (29)	21(3)
	2	67 (70)	8 (5)
	3	77 (72)	19 (17)
	4	67 (12)	38 (9)

[1] Number in parenthesis is number of dead plants for a group.

[2] Willow was not found in areas with low natural fuels.

Effects of Silviculture Treatment and Burning on Survival of Bitterbrush and Willow. By the fall of 1993 it was apparent that the shelterwood cut and burn treatments decreased survival of bitterbrush and willow (Fig. 3). Bitterbrush and willow survival were reduced ($p<0.05$) in the burn treatments and shelterwood cut as compared to the control . The combined effects of timber harvesting and burning lowered bitterbrush survival ($p<0.05$) as compared to the no burn treatment; however, there were no differences in willow survival ($p>0.05$) between the shelterwood cut and burn treatments. Bitterbrush density and abundance averaged 35% of pre-treatment levels for the burn treatments. Willow density and abundance were less affected by burning treatments and averaged 77% of pretreatment levels.

There was an increase in vigor of bitterbrush ($F=215$, $p<0.001$) and willow plants in the burn and logging treatments ($p<0.05$) (Table 7). Increases in vigor were greater in the burn treatments than in the logging treatments for both bitterbrush ($F=11.8$, $p=0.001$) and willow ($p<0.05$). Non-parametric regression analysis using Kendall-tau coefficient was used to determine the association of vigor with height, diameter, dead class, mechanical damage, fuel loading, and dead class for those plants not receiving burn damage (Table 8). For both bitterbrush and willow, vigor was negatively correlated with mechanical damage and dead class for the plants not exposed to fire. For plants exposed to fire, we did not find any significant correlations.

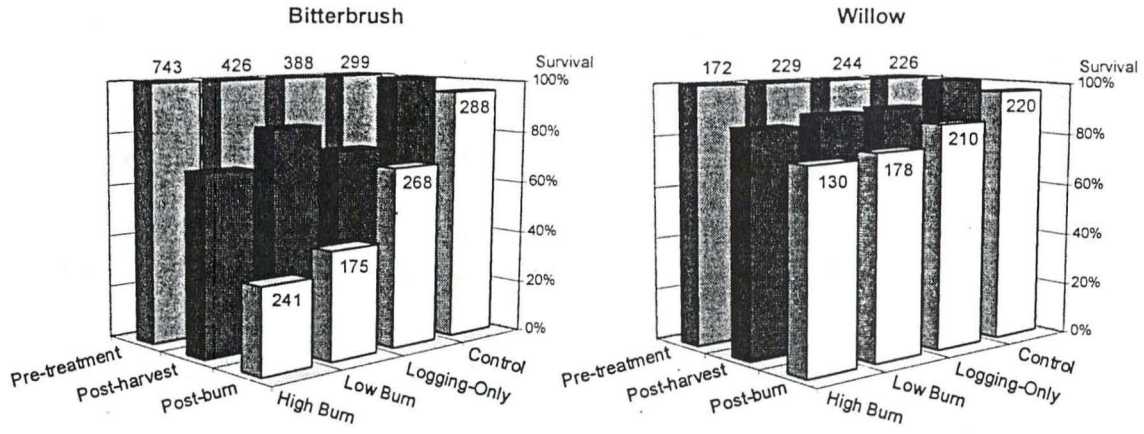

Fig. 3. Survival of antelope bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants in 1994 following treatments in Lick Creek Demonstration Area.

Table 7. Proportion of bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants in the 0.10 acre permanently established sub-plots in each vigor class in 1994.

	BITTERBRUSH VIGOR			WILLOW VIGOR		
TREATMENT	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
Control	33%	51%	16%	15%	62%	23%
No Burn	95%	4%	1%	60%	28%	11%
Low Cons. Burn	99%	0%	1%	71%	22%	6%
High Cons. Burn	82%	14%	4%	69%	23%	8%

Table 8. Correlation of bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) vigor with independent variables in LCSA, 1994.

Species[1]	N	Variables[2,3]	Kendall t	Significance
Bitterbrush	792	Mechanical damage	0.23	p<0.001
		Dead class	-0.10	p=0.001
		Height	-0.09	p=0.001
Willow	466	Mechanical damage	0.39	p<0.001
		Dead class	-0.07	p=0.05

[1]These are plants not exposed to fire. There were no significant correlations for plants exposed to fire.
[2]Variables used were height, diameter, dead class, mechanical damage, fuel loading, and burn class.

Seedlings. Scouler's willow, as all species in the Salicaceae, is dioecious with pollination generally by insects. These shrubs developed aments before the leaves, but there were plants on the site that appeared coetaneous. There were no seedlings located in 1993 and only 5 willow seedlings documented in 1994. Flower and fruit production were extremely low on the site, but by 1995 there were a few areas where seedlings were common. For the low and high consumption burn treatments the mean seedling numbers were 1.4 and 1.3 plants/0.1 acre plot. However, seedling numbers/plot varied from 0 to 23 seedlings. The only unit where most of the plots (60%) had seedlings was Unit 9. Unit 9 was the most mesic of the units that received a burn treatment and this area may have been more conducive to seedling survival. For all other burn units frequency of plots with seedlings was less than 18% which provides evidence that seedling success was very low. In 1995 we counted only 15 willows with flowers. Twelve of these plants were protected by cages and had been burned. Seedlings were not found on the control and were limited to a few scarified sites (not in the 0.1 acre plots) on the shelterwood cut treatment.

Bitterbrush has perfect flowers and produces a pubescent achene as the fruit. Bitterbrush flowered in late spring and the fruit was present on a few shrubs from summer to late summer. Flower production was observed on several plants, but was limited and more prevalent on shrubs protected from browsing and on more open areas (shelterwood cuts). Fruit production was more limited for unknown reasons and may be an important factor in the almost complete lack of seedlings. There were no recorded

bitterbrush seedlings in 1993, 8 in 1994 and 16 in 1995. In 1995, 16 bitterbrush seedlings were located, but only 2 of these were actually on the 0.10 acre plots. Of these, 13 bitterbrush seedlings were found growing together and were probably a squirrel and chipmunk cache.

Sub-study 2. Effect of silviculture treatment and fuel loading class on leaf and twig production and nutritive value of permanently marked plants.

In 1993 bitterbrush mortality was estimated at 68% and 89%, respectively for the low consumption and high consumption burn treatments when averaged across fuel loadings. In 1994, mortality decreased slightly because of regrowth on 6 plants previously recorded as dead (Table 9). In both 1993 and 1994 a comparison of mortality using multiple analysis of variance with fuel loading and treatment as independent variables showed that bitterbrush mortality was greatest for plants with a heavy fuel loading, independent of burn treatment (X^2=34.1, $p<0.001$, low burn; X^2=8.2, $p<0.01$, high burn) (Table 9). Bitterbrush with a light fuel loading, however, showed significantly higher mortality in the high consumption burn than the low consumption burn (X^2=7.0, $p<0.01$).

Growth of bitterbrush was also reduced by burning. Current year's standing crop of burned bitterbrush averaged 1.7 g in 1993 and 3.3 g in 1994 compared to 3.6 and 4.6 g for unburned bitterbrush in those years (Fig. 4). In 1993, mean biomass of bitterbrush in the high consumption burn was significantly lower than other treatments

Table 9. Number of surviving bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants (no. total plants) for each fuel loading in the burn treatments for the LCSA, 1994.

Burn Treatment	Fuel Class[1] -Willow		Fuel Class -Bitterbrush		
	Added	Heavy	Added	Heavy	Light
Low Consumption	13(19)[a]	17(18)[c]	1(16)[d]	2(15)[d]	15(16)[e]
High Consumption	16(17)[bc]	14(16)[bc]	0(15)[d]	3(16)[d]	8(14)[f]

[1] Willow plants with a light fuel load were not located.

[2] Mortality is significantly different ($p<0.05$) when followed by a different letter using orthogonal comparisons for each species.

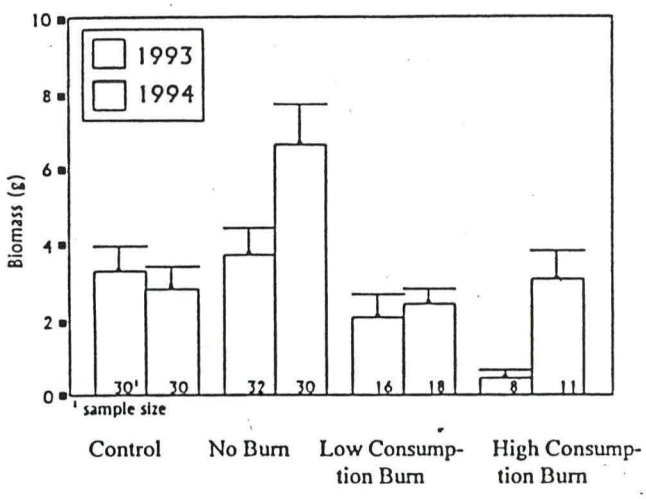

Fig. 4. Mean biomass (g) and one standard error (Se) of bitterbrush (*Purshia tridentata*).

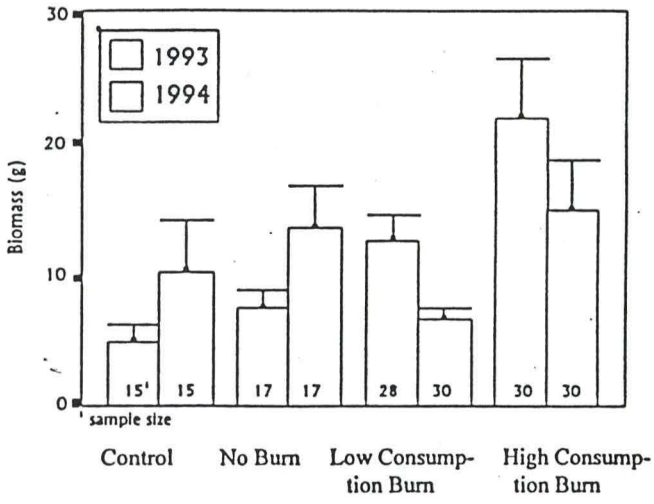

Fig. 5. Mean biomass (g) and one standard error (Se) of Scouler's willow (*Salix scouleriana*).

(F=4.8, P<0.05). However, in 1994 mean biomass in the no burn treatment increased, resulting in a significant difference between this and other treatments (F=6.1, P=0.001) (Fig. 4).

Willow responded differently to the burning with much less mortality and a stimulation of regrowth for surviving plants. A comparison of mortality using multiple analysis of variance with fuel loading and treatment as independent variables showed that willow with added fuel had higher mortality in the high consumption burn compared to the low consumption burn (X^2=4.5, p<0.05). In 1994, plants with an added fuel loading had higher mortality than those with a heavy fuel loading in the low consumption burn (X^2=4.2, p<0.05).

In 1993, mean biomass for willow plants was significantly less in the control (F=8.5, P<0.01) and the logging treatments (F=4.7, P<0.05) compared to the burn treatments. However, in 1994 the only significant difference in biomass was between the low and high consumption burns (F=5.9, P<0.05) (Fig. 5). There was an increase in biomass in the control and logging treatments in 1994 (P<0.05) that was not seen in the burn treatments. Instead, heavy browsing during summer and fall of 1993 resulted in declines in biomass in the burn treatments.

Fuel loading did not significantly influence standing crop for bitterbrush or willow (P=0.27 for bitterbrush; P=0.84 for willow).

Nutrition. There were no significant differences in any of the nutritional analyses for bitterbrush (Table 10). For willow there were significant treatment and year differences. Carbon (%) was lower for willow in the burns compared to the no burn and control treatments in 1994 but increased to levels similar to those in the no burn and control treatments in 1995. Phosphorus was higher in the burn treatments. For the no burn treatment lignin was higher than for the burn or control treatments.

DISCUSSION

Bitterbrush and willow were significantly influenced by the no burn and prescribed fire treatments. The 35% mortality of bitterbrush from the shelterwood cut seemed high; however, it was much less than the 72% reported by Edgerton (1982) after a shelterwood cut of lodgepole pine in Oregon. In Edgerton's study tree basal areas was reduced by 78% compared to the 53% reduction in this study. Additionally, skid trails disturbed only 10% of the site compared to 46% in the shelterwood cut of lodgepole pine (Edgerton 1982).

Willow mortality from logging was low compared to bitterbrush. Morphology of willow plants differs considerably from bitterbrush in that it has a deeper root system and is multi-stemmed, and is therefore more tolerant to disturbance. Also, willow often resprouts after surface disturbance from a subterranean root crown (Lyon 1966), but bitterbrush can only resprout from a surface caudex (Guinta et al. 1978), which is more easily removed by disturbance. Of the plants that were recorded in a skid trail and severely damaged, 20% of willow resprouted compared to only 4% of bitterbrush.

Table 10. Nutrient analysis of bitterbrush and willow twigs collected during winter of 1994 and 1995, plus a sample of willow twigs collected spring after a fall burn off-site.

	% CARBON		% NITROGEN		% PROTEIN		% ASH		% ORGANIC MATTER		Phosphorus (PPM)		% ADF		% cellulose		% lignin	
	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
WILLOW																		
Burns	47.64	50.02	1.09	1.20	6.82	7.51	3.40	4.23	96.60	95.78	1755.2	1922.3	56.52	37.56	33.94	20.59	22.28	16.70
NO BURN	49.68	49.20	1.05	1.09	6.54	6.80	2.39	4.65	96.87	95.35	1573.8	1647.8	56.20	42.82	29.80	22.90	26.19	19.75
CONTROL	48.82	49.96	0.96	1.10	6.03	6.90	3.31	4.59	96.69	95.41	1533.8	1628.3	56.54	42.59	32.81	22.12	23.56	20.32
EARLY BURN	n/a	47.68	n/a	0.99	n/a	6.16	n/a	3.59	n/a	96.41	n/a	1578.3	n/a	52.46	n/a	33.93	n/a	18.44
BITTERBRUSH																		
BURNS	n/a	48.46	n/a	1.37	n/a	8.55	n/a	2.70	n/a	97.31	n/a	1364.5	n/a	43.64	n/a	23.01	n/a	20.42
NO BURN	49.33	49.24	1.21	1.44	7.57	9.01	2.42	2.64	97.59	97.37	1233.5	1620.5	53.20	43.69	25.98	21.59	27.02	21.98
CONTROL	49.29	48.79	1.25	1.35	7.79	8.45	2.45	2.72	97.55	97.29	1330.5	1347.0	51.66	43.57	26.67	20.96	24.76	22.51

For both species, mortality losses from logging were partially offset by increases in biomass and vigor of surviving plants (Table 11 and 12). Willow increased in both biomass and vigor in the logging treatment relative to the control, although these increases were not as great as in the burn treatments. However, for bitterbrush the reduction in overstory competition, and subsequent increase in light resulted in a substantial increase in lateral and terminal growth of bitterbrush twigs. This is consistent with other research that found an increase in current annual growth following logging for up to 7 years after overstory removal (McConnell and Smith 1970, Stuth and Winward 1976, Edgerton 1982). In this study, increases in lateral and terminal growth of bitterbrush twigs was reflected in an increase in vigor. Overall, these changes in biomass and vigor of bitterbrush and willow document a positive response to overstory reduction for surviving plants.

Response of bitterbrush and willow to prescription burning varied. Bitterbrush mortality from the burning treatments was high (59% and 68% for the low consumption and high consumption burn treatments) which is consistent with results from other studies. Clark et al (1982) found 90% mortality of bitterbrush after burning in a ponderosa pine stand in Oregon and Blaisdell and Mueggler (1956) found a 50% morality in shrublands of the Snake River Plain, Idaho. Cook et al (1994) found 41%, 61% and 100% mortality at three different burns in mountain-shrub in Wyoming and Kituku et al (1992) reported 10-50% mortality in their sites following a burn in a Wyoming shrub grassland. It is interesting to note that bitterbrush mortality was estimated at 81% in the fall after the burns; but, resprouting the second year after

Table 11. Site characteristics for Scouler's willow (*Salix scouleriana*) by type of treatment in LCSA, 1994.

Treatment	% Cover(Δ)	Δ (Plants/ha)[a]	Mean Biomass (g/plant) Browsed	Mean Biomass (g/plant) Unbrowsed	Plants with High Vigor
CONTROL	0.8 (-1%)	-3% (151)	10.3	9.9±2.9	15%
NO BURN	0.2 (-33%)	-14% (146)	13.7	11.8±1.5	60%
LOW BURN	0.3 (-62%)	-22% (124)	5.5	10.6±2.6	71%
HIGH BURN	0.5 (-58%)	-30% (91)	13.7	22.1±3.2	69%

Table 12. Site characteristics for bitterbrush (*Purshia tridentata*) by type of treatment in LCSA, 1994.

Treatment	% Cover(Δ)	Δ (Plants/ha)	Mean Biomass (g) Browsed	Mean Biomass (g) Unbrowsed	Plants with high vigor
CONTROL	0.7 (-2%)	-1% (202)	2.9 g	2.7± 0.7	28%
NO BURN	0.3 (-75%)	-31% (183)	6.7	7.9± 1.6	70%
LOW BURN	0.1 (-83%)	-60% (116)	2.5	4.4± 0.5	88%
HIGH BURN	0.1 (-92%)	-69% (168)	3.1	5.2± 1.5	78%

treatment was significant with 57 of the bitterbrush plants recorded as dead in 1993 resprouting in 1994. Blaisdell and Mueggler(1956) also reported similar findings for bitterbrush plants that resprouted as late as 13 months after a burn. The ability of some bitterbrush to resprout following a burn may be explained by factors such as variation in fire prescription (Blaisdell and Mueggler 1956, Buwai and Trlica 1977, Driver et al 1980), abiotic conditions (Driscoll 1963, Adams 1980, Thompson Hobbs and Schimel

1984), and plant phenology (Menke and Trlica 1981). For example, spring burning has been reported to enhance sprouting (Blaisdell and Mueggler 1956, Adams 1980, Driver et al 1980, Martin and Driver 1983) and reduce mortality (Wright et al. 1979); whereas, a fall burn favors plant regeneration by seed (Fisher and Bradley 1987). Apparently, however, plant structure explains most of the variation in bitterbrush response to fire found in the literature. The recumbent ecotype can sprout after fire (Blaisdell and Mueggler 1956, Driscoll 1963, Wright et al 1979) whereas the columnar ecotype is a non-sprouter, relying on seedling regeneration from on- and off-site seeds (Wright et al 1979, Noste and Bushey 1987). For this research, the combination of a spring burn, heavy summer precipitation (18.5 cm, June through August) and cool summer temperatures (average daily temperature of 14^0) following the burn were favorable conditions for bitterbrush to resprout (Driscoll 1963, Nord 1965, Ferguson 1972). However, resprouting was low because the bitterbrush found on this site is the columnar, non-sprouting ecotype.

As expected, fuel loading influenced mortality by affecting fire severity (Adams 1980). Driver et al. (1980) reported that 40-100% of bitterbrush with light fuel loadings resprouted following a burn, but no resprouting occurred for bitterbrush with heavy or added fuel loadings. Also, fuel loading has a higher correlation with mortality than with productivity (Driscoll 1963), which is consistent with our results showing a significant effect of higher fuel loading on mortality but not on vigor.

Although fire causes high mortality for bitterbrush, it does create litter-free sites

necessary for seed germination from rodent caches (Clark et al 1982). Sherman and Chilcote (1972) found that in central Oregon ponderosa pine forests, rodent caches are a significant source of seeds for seedling establishment of bitterbrush. In this stand, we found only 8 and 16 bitterbrush seedlings in the summers of 1994 and 1995. Although not measured, we believe that bitterbrush seed production was extremely low, probably associated with initial poor vigor of plants and heavy browse use by wild ungulates. The reduction of understory competition following timber harvest or prescribed fire would enhance seedling establishment (Holmgren 1956) if seeds were available for germination (which was apparently not the case on this site). Only additional data collection would determine if bitterbrush seedling establishment increases over time.

For bitterbrush plants in the no burn treatment, vigor and biomass increased, especially by 1994. We believe there was an increase in bitterbrush growth on the burn treatments (observed in 1995 but no data collected). The delayed increase in growth may be related to increases in inorganic nitrogen following the fire (Hobbs and Schimel 1984).

We found no difference in bitterbrush nutrition between treatments, but sample size was low reducing our ability to make sound comparisons. A comparisons of means reveal no trends in increased nutrition for burned bitterbrush as compared to the controls. Kituku et al (1992) reported an increase in nutritional value of post-burn bitterbrush sprouts compared to controls. Kituku et al (1992) hypothesized that these increases in N, P and ash indicate greater leaf:stem ratios. The extensive browsing of

bitterbrush probably lowered leaf to stem ratios of bitterbrush in our study area. Generally, the resprouts following burning were heavily browsed leaving little growth to maintain vigor. Buwai and Trlica (1977) found a decrease in vigor, biomass, and total nonstructural carbohydrates of all shrubs, including bitterbrush, subject to grazing as compared to the controls in shrub-grasslands in northern Colorado. It is likely that the heavy browsing during the spring and summer following treatment had a significant impact winter browse quality.

Mortality of willow due to burning was low (19%) and the vigorous resprouting after burning is consistent with other studies (Leege and Hickey 1971, Leege 1972, 1979). Willow has exhibited as much as a 100% increase in biomass and vigor after burning (Noste and Bushey 1987, Leege 1969, Mueggler 1965). Willow is a seral species, colonizing rapidly after fire, and has been reported to increase in production at least 10 years after a fire (Stickney 1986). The vigorous regrowth of willow and the high mortality of bitterbrush suggest that prescribed fire as a silvicultural practice is much more effective in increasing biomass and vigor of willow as compared to bitterbrush.

Willow seedlings were much more prevalent in 1995, but only one unit (number 9) had a high percentage (60%) of plots containing seedlings. Therefore, seedling success three years post-treatment was considered quite poor. Flowering and fruit production were apparently affected by the heavy browsing and most plants with flowers were protected by cages.

Nutritional quality of willow in 1995 was improved by burning compared to control plants as shown by increases in phosphorus, crude protein, and decreased lignin. In northern Idaho willow also showed an increase in nutrient content one and two years after the burn (Leege 1972). Asherin (1973) also found an increase in willow fat and phosphorus content after burning. Overall digestibility increased with increases in moisture and crude protein, as well. However, Canon et al (1987) found that willow did not differ significantly in crude protein or IVDM between burned and non-burned sites but prescribed burning may increase the quality of winter diets even without a change in nutritional quality of plants. For example, Hobbs and Spowart (1984) found that mule deer winter quality diet improved substantially in a burned mountain shrubland despite small changes in the quality of individual forages. The change in forage quality was attributed to a change in forage selection patterns in the burn areas.

Elk, moose and mule deer were seen on the study site in both the winter and the summer. Browsing was extensive throughout the year and difficult to assess, although frequency and intensity was apparently consistent with availability. Willow was utilized extensively on the burn treatments, whereas bitterbrush was browsed most heavily on the no burn/logging treatment. Heavy willow browsing occurred during summer immediately after the burns of willow which would be expected to decrease vigor and complicate analysis of changes in nutritional quality. Canon et al (1987) also found that willow was heavily browsed immediately following fire in a Douglas fir/aspen stand burned in southeast Idaho.

MANAGEMENT IMPLICATIONS

The no burn/shelterwood cut improved vigor and productivity of bitterbrush; however, the 32% mortality on the shelterwood cut and lack of seedlings for all treatments would be a concern if maintaining or increasing bitterbrush numbers was a major management objective. It is our speculation that the low vigor of the bitterbrush prior to treatment and the subsequent heavy browsing following treatment was a major reason for the lack of fruit production and seedlings on this site. Biomass and vigor measurements were not done in 1995, but bitterbrush growth appeared much greater and vigorous in treated stands as compared to 1992-94.

Willow responded more favorably to burning with increased biomass and vigor. However, few Scouler's willow seedlings were observed and thus the density of willow on the site actually decreased. Ungulate browsing probably reduced measured vigor and certainly flower/ fruit production by removing a significant proportion of new growth.

Additional data collection is needed to determine the long-term response of these browse species to the treatments. Flower and fruit production were apparently increasing in 1995. Although only 99 total seedlings were observed in 1995, this is quite an increase from the 8 seedlings located in 1994. Ungulate browsing during the summer of 1995 appeared to be much lighter than 1993 and 1994, especially for willow.

Because bitterbrush and willow responded differently to the treatments, it is evident that plant response to these silviculture prescriptions on a stand level is species-specific. In areas where both willow and bitterbrush occur, land and resource managers interested

in enhancing browse quality need to consider understory species composition and desired plant characteristics (density, biomass, vigor, etc.) before applying treatments. Tables 11 and 12 provide a summary of the effects of the treatments on willow and bitterbrush. Reducing the impacts of logging and prescribing low consumption burns could reduce plant mortality while still resulting in overall greater productivity of bitterbrush and willow. Another large consideration is the potential impact of ungulates. Treatment size should be large where heavy browsing may occur and/or some plants may need to be protected from browsing to allow for rapid recovery and seed production.

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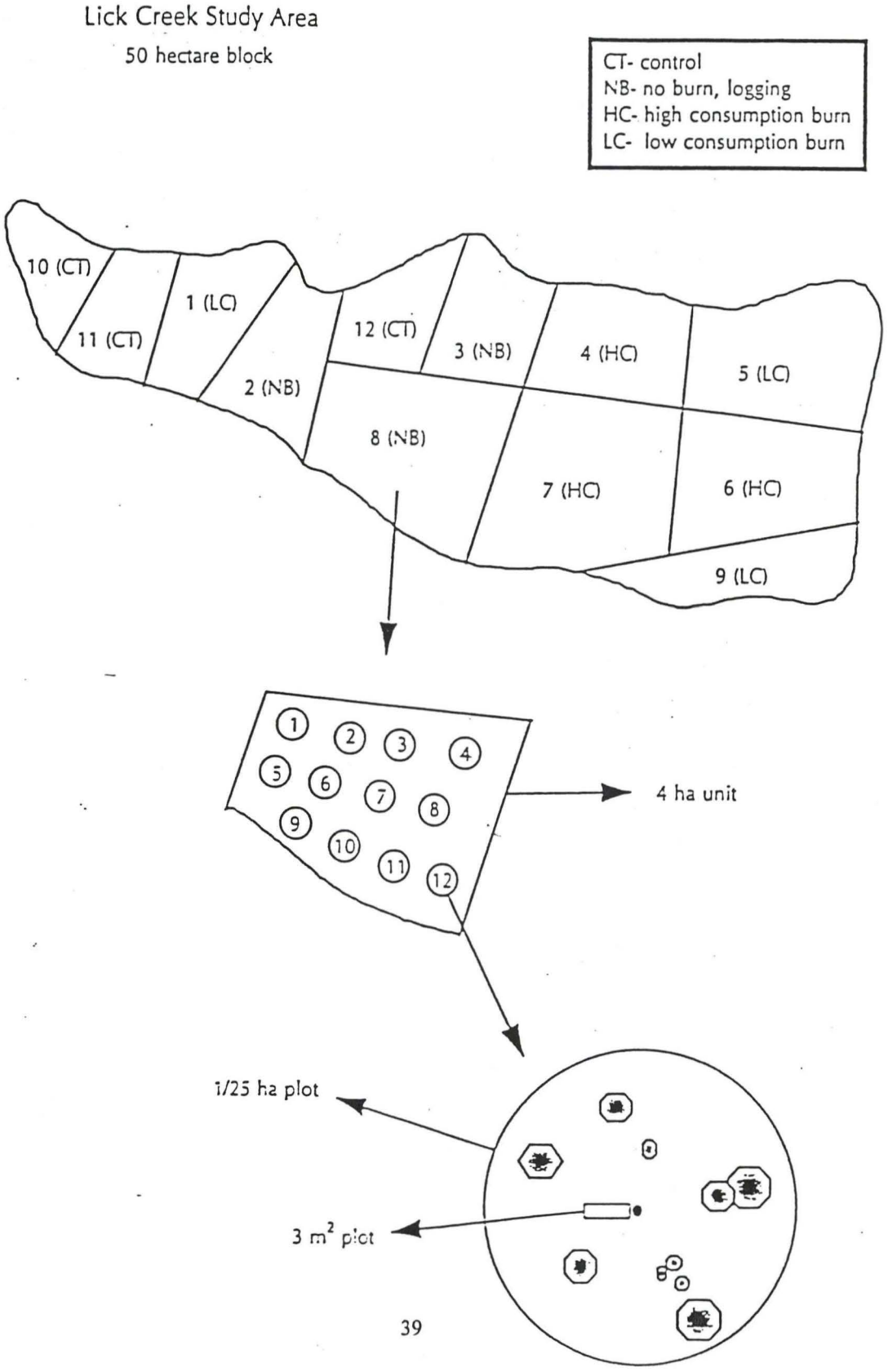
Appendix A. Influence of burn treatments on duff consumption.

Duff consumption averaged 20% and 40% for the low consumption and high consumption burn treatments, respectively. In the low consumption burn duff consumption near individual bitterbrush plants for the light, heavy, and added fuel treatments averaged 32%, 71%, and 86%, respectively. In the high consumption burn the light, heavy, and added fuel treatments resulted in a 45%, 82%, and 96% duff reduction. Near individual Scouler's willow in the low consumption burn duff reduction in the heavy and added fuel treatments averaged 79% and 93%, respectively compared to a 94% and 100% duff reduction for the high consumption burn.

Appendix B. Study plot diagram.



Appendix C. Bitterbrush mortality (%) in each burn class and mechanical damage class for plants in the high consumption and low consumption burn treatments.

Mechanical Damage	BURN CLASS None	Slight	Moderate	Severe	Very Severe
None	11 (95)	55 (149)	68 (41)	100 (38)	93 (29)
Slight	1 (46)	50 (48)	54 (37)	94 (34)	74 (19)
Moderate	6 (49)	59 (34)	78 (27)	84 (63)	92 (13)
Severe	7 (30)	64 (11)	77 (13)	80 (46)	92 (13)
Very Severe	29 (7)	50 (2)	100 (3)	93 (15)	100 (4)
Skid	89 (303)				

Appendix D. Willow mortality (%) in each burn class and mechanical damage class for plants in the high consumption and low consumption burn treatments.

Mechanical Damage	BURN CLASS None	Slight	Moderate	Severe	Very Severe
None	0 (2)	0 (11)	4 (22)	23 (53)	100 (3)
Slight	0 (1)	0 (4)	13 (23)	21 (68)	82 (9)
Moderate	50 (2)	25 (4)	13 (15)	15 (60)	100 (3)
Severe	0 (6)	0 (4)	0 (7)	10 (31)	100 (1)
Very Severe	33 (01)	nd	0 (1)	31 (13)	0 (3)
Skid	52 (26)	nd	nd	nd	nd

Appendix E. Plant vigor measurements in 1994.

Proportion of bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants in the 0.10 acre permanently established sub- plots in each vigor class in Lick CSA, 1994.

	BITTERBRUSH			WILLOW		
TREATMENT	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
Control	33%	51%	16%	15%	62%	23%
Logging	95%	4%	1%	60%	28%	11%
Low burn	99%	0%	1%	71%	22%	6%
High burn	82%	14%	4%	69%	23%	8%

Number of bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants in each mechancial damage class by vigor class in LCSA, 1994.

	BITTERBRUSH			WILLOW		
Mechanical Damage	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH
None	92	233	316	67	187	98
Slight	9	12	95	12	23	85
Low	7	15	82	8	18	89
Medium	3	3	44	1	20	50
High	1	4	11	6	12	33
Severe	7	4	34	2	5	22

Number of bitterbrush (*Purshia tridentata*) and Scouler's willow (*Salix scouleriana*) plants in each burn class by vigor class in LCSA, 1994.

	BITTERBRUSH			WILLOW		
Burn Class	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH
None	107	265	420	78	202	186
Low	11	3	96	0	8	14
Medium	0	1	38	2	10	50
High	1	1	20	16	43	124
Severe	0	1	8	0	2	3